First Experience with an HOM Coupler for the 56 MHz Quarter Wave SRF Cavity

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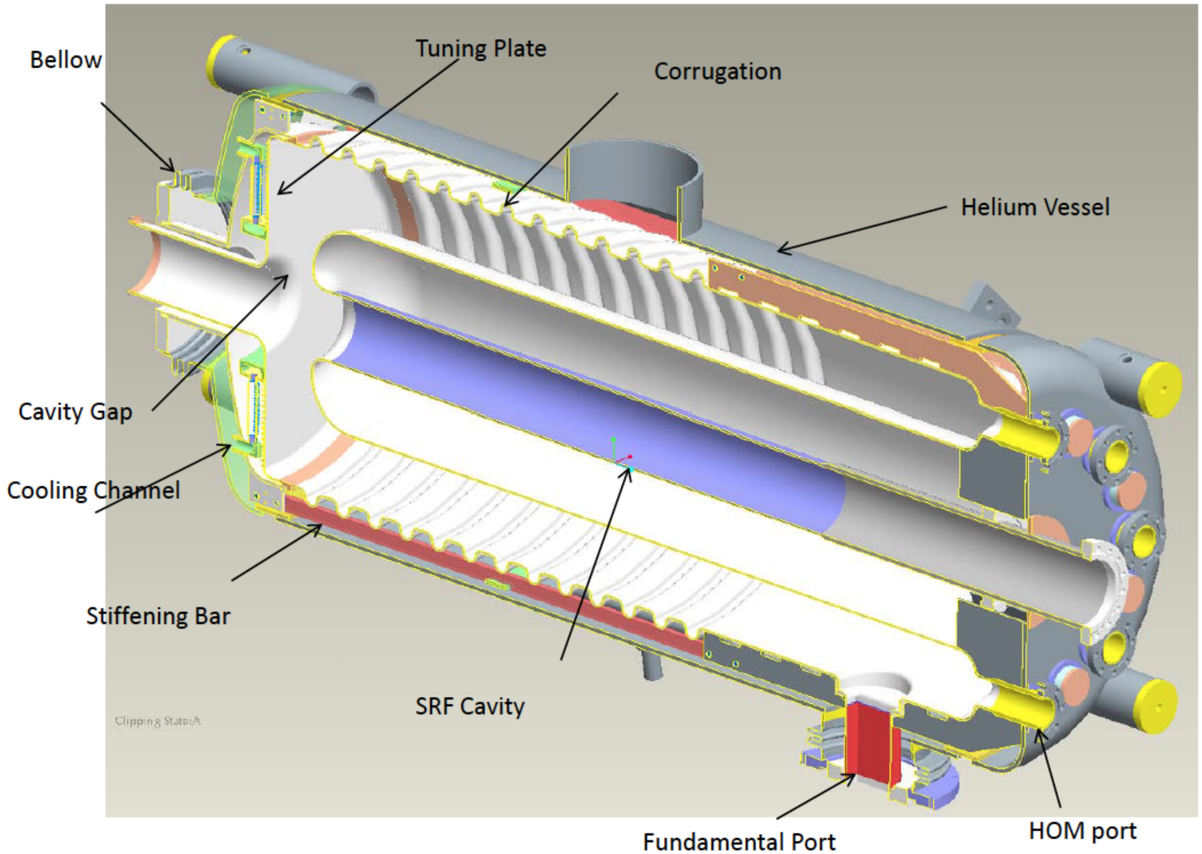
Outline

- Introduction of the 56 MHz SRF cavity
- HOM damper design
- High-pass filter
- Tuning of the filter
- Cooling
- Measurement of the damper assembly
- Summary

56 MHz – Storage Cavity for RHIC



- The 56 MHz cavity is a niobium superconducting quarter wave resonator. It is a beam driven cavity.
- The cavity will increase the RHIC luminosity by providing 5 times larger RF buckets.
- The cavity does not have a large tuning range to follow the frequency change during particle acceleration, so it is turned on only after acceleration for re-bucketing during store, hence the name "storage cavity.".

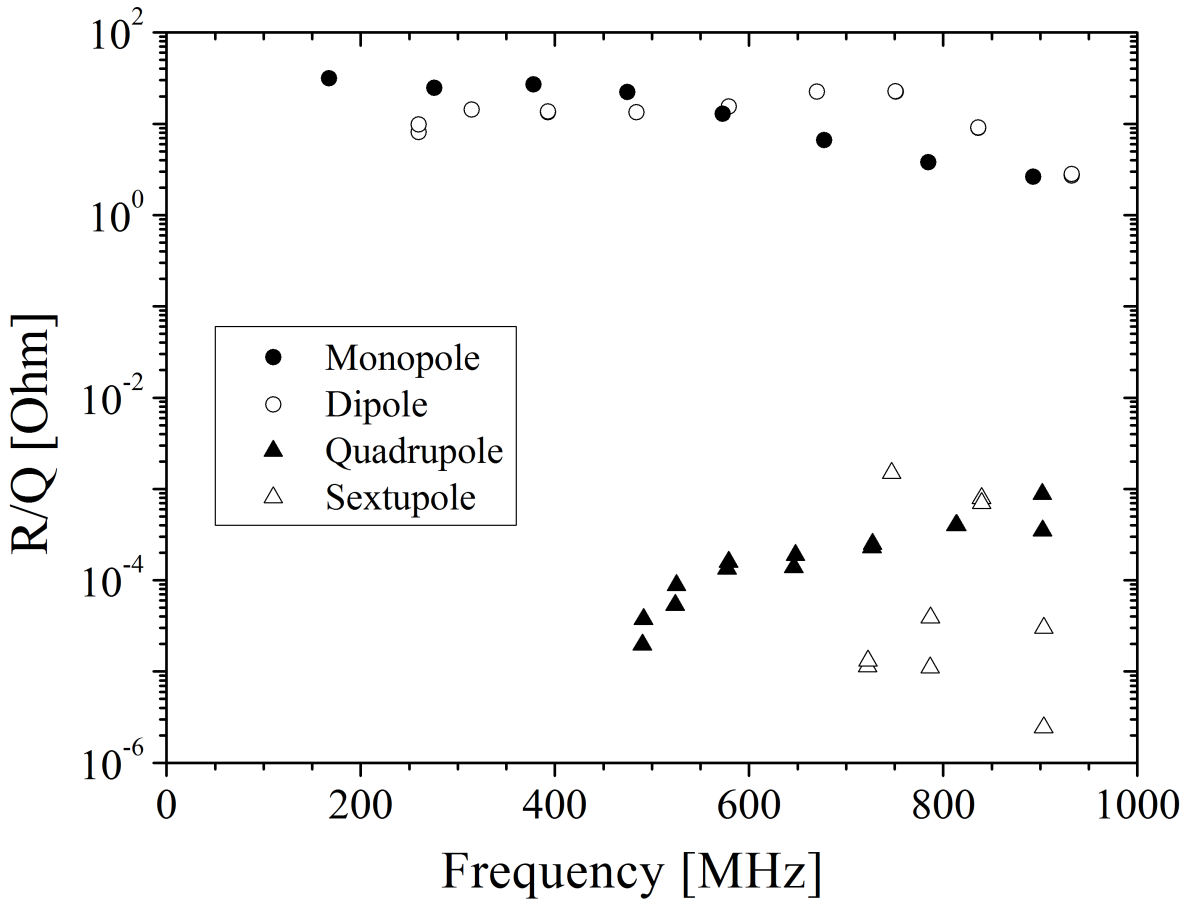
56 MHz – Storage Cavity for RHIC

- A 1 kW amplifier is connected to the cavity to:
  i. achieve required amplitude and phase stability;
  ii. provide conditioning capability;
  iii. make up power for intrinsic losses.
- The cavity fundamental mode is detuned and strongly damped during injection and acceleration.
- At the energy of experiment, first the fundamental damper is withdrawn and then the cavity frequency is tuned (approaching from below the beam harmonic) to achieve operating voltage of 2.0 MV.
- A piezo tuner is employed to compensate any fast frequency changes.

56 MHz Cavity Parameters (at 2 MV)

Stored Energy	139	Joules
Operating temperature	4.2	K
Power dissipation (10 nOhm residual surface resistivity)	42	W
Q_0	1.4E9	
Q_L	4E7	
R/Q (accelerator notation)	80.5	Ohm
Maximum surface electric field	41.6	MV/m
Maximum surface magnetic field	112.6	mT
Tuning sensitivity of mechanical tuner	17	kHz/mm
Coarse tuning range	25.5	kHz
Coarse tuning speed	3666	Hz/sec
Fine tuning range by piezo drive	60	Hz
Fine tuning resolution	0.06	Hz/Volt
Lorentz Detuning	148	Hz

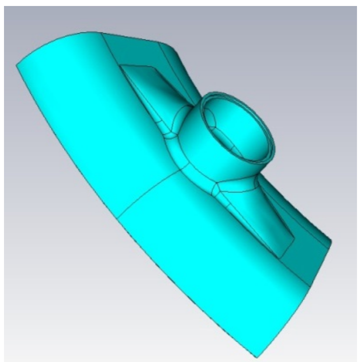
Cavity HOMs

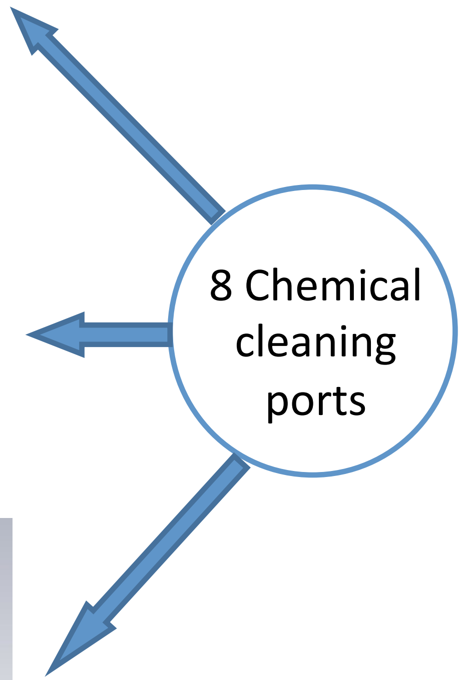


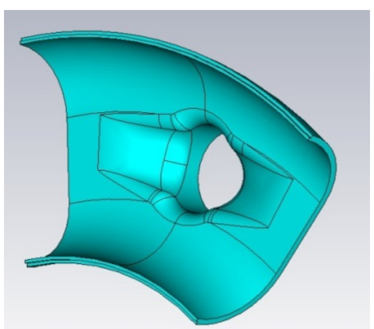
The *R/Q'*s of monopole and dipole modes are distributed in the range between 1 and 100 Ohm, while the R/Qs of quadrupole and sextupole modes are all below 10^{-2} Ohm. Therefore, while the effective damping for all modes is important, the monopole and dipole modes are more critical than the other two types.

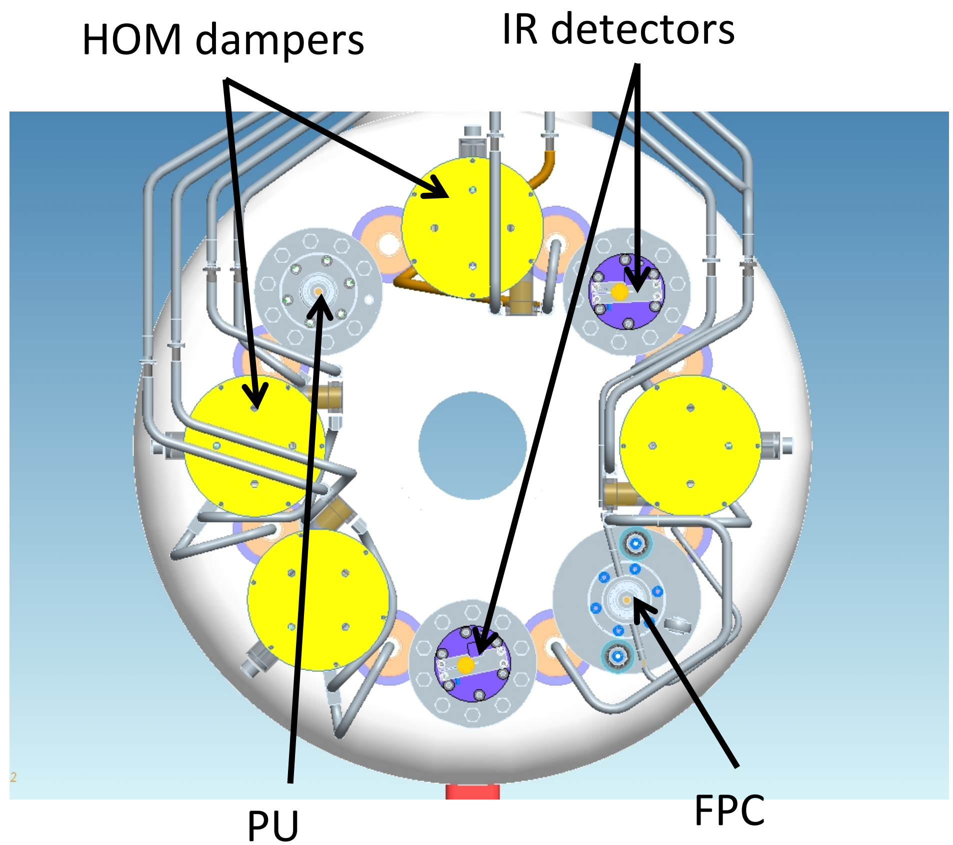
Coupler Ports

The cavity has 8 chemical cleaning ports at the rear end. The ports are occupied by 4 HOM dampers, 1 fundamental power coupler (FPC), 1 pickup probe, and 2 IR quench detectors.

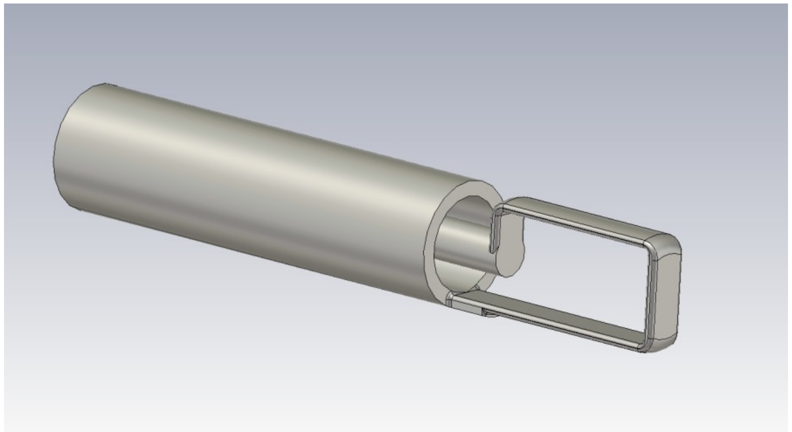




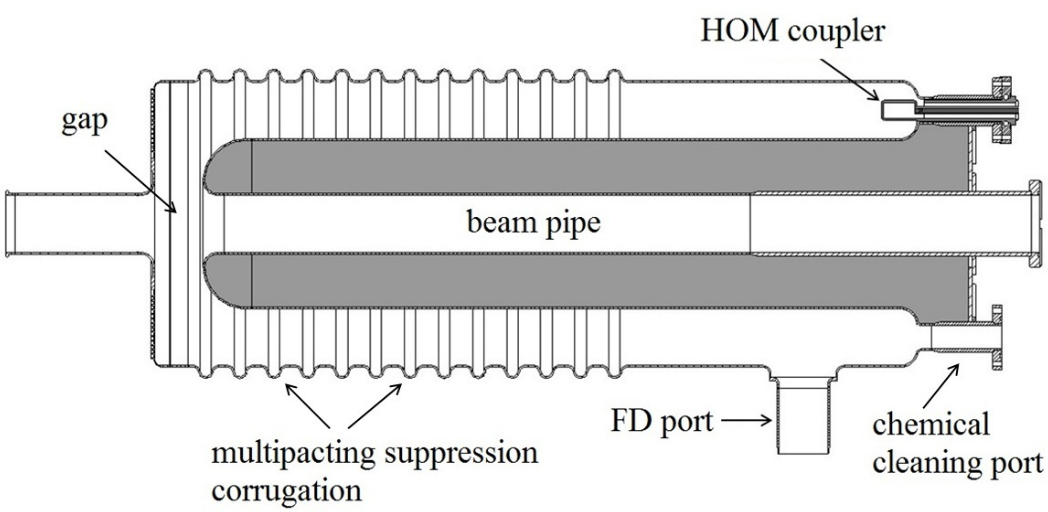




HOM Damper Design



Dimension of damper inner loop	6 cm x 2.88 cm
Damper width	2 cm
Damper thickness	0.3 cm
Inner conductor radius	0.76 cm
Port radius	1.74 cm

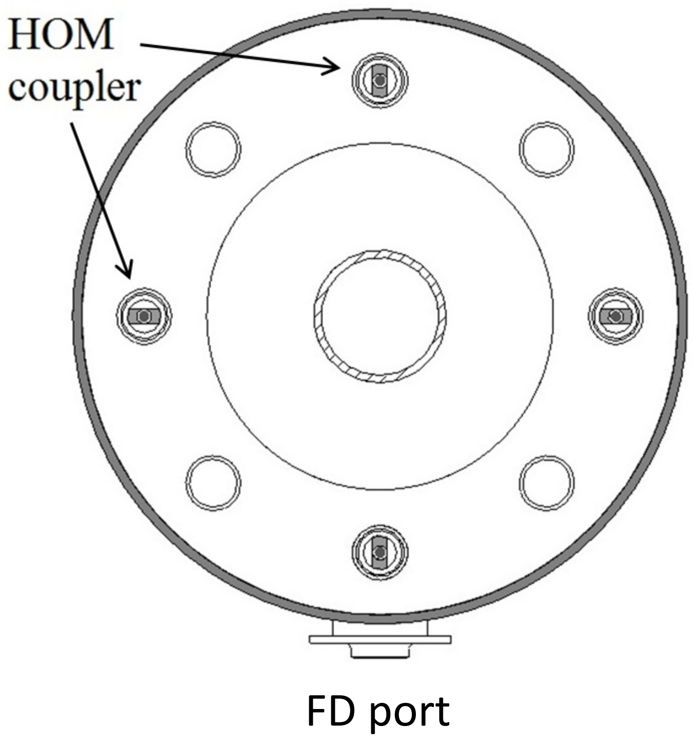


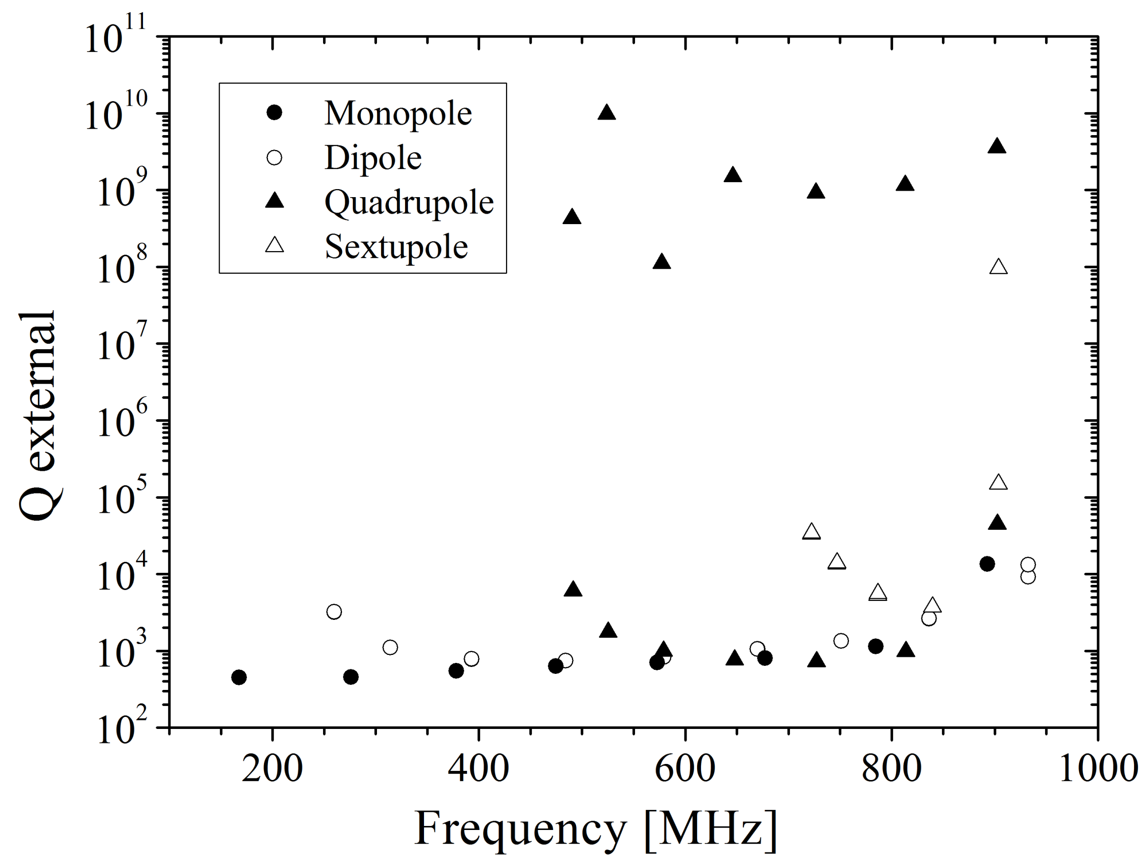
HOM dampers:

- Inserted from the chemical cleaning ports at the rear end of the cavity;
- Are of a rectangular loop shape with magnetic coupling;
- Peak magnetic field on the damper is at the same level as the cavity peak surface magnetic field;
- No multipacting found in simulations.

HOM Coupler Configuration

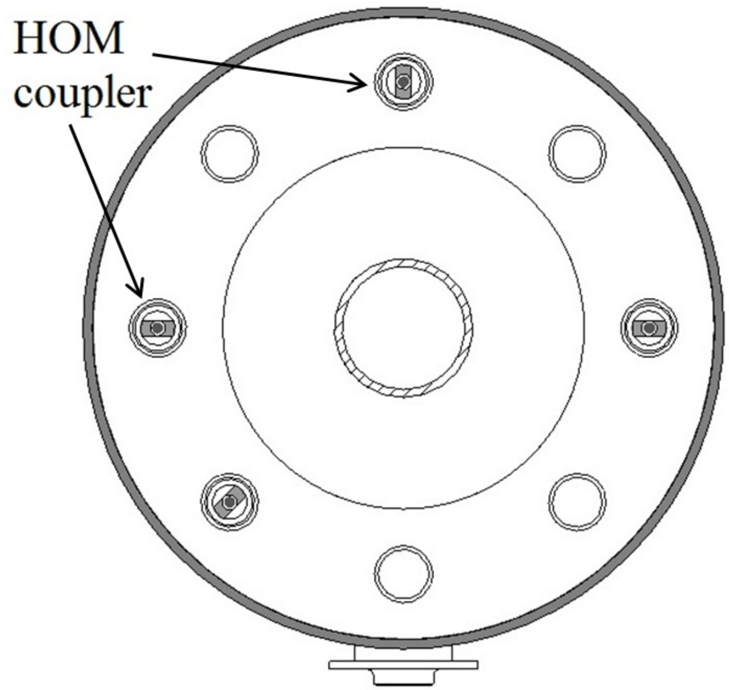
- On the cavity, the FD port breaks the 2D symmetry along the beam axis, therefore the orientation of the multipole modes are determined accordingly.
- With symmetrical coupler configuration, the quadrupoles that are oriented at 45 degrees with respect to HOM couplers will be insufficiently damped.

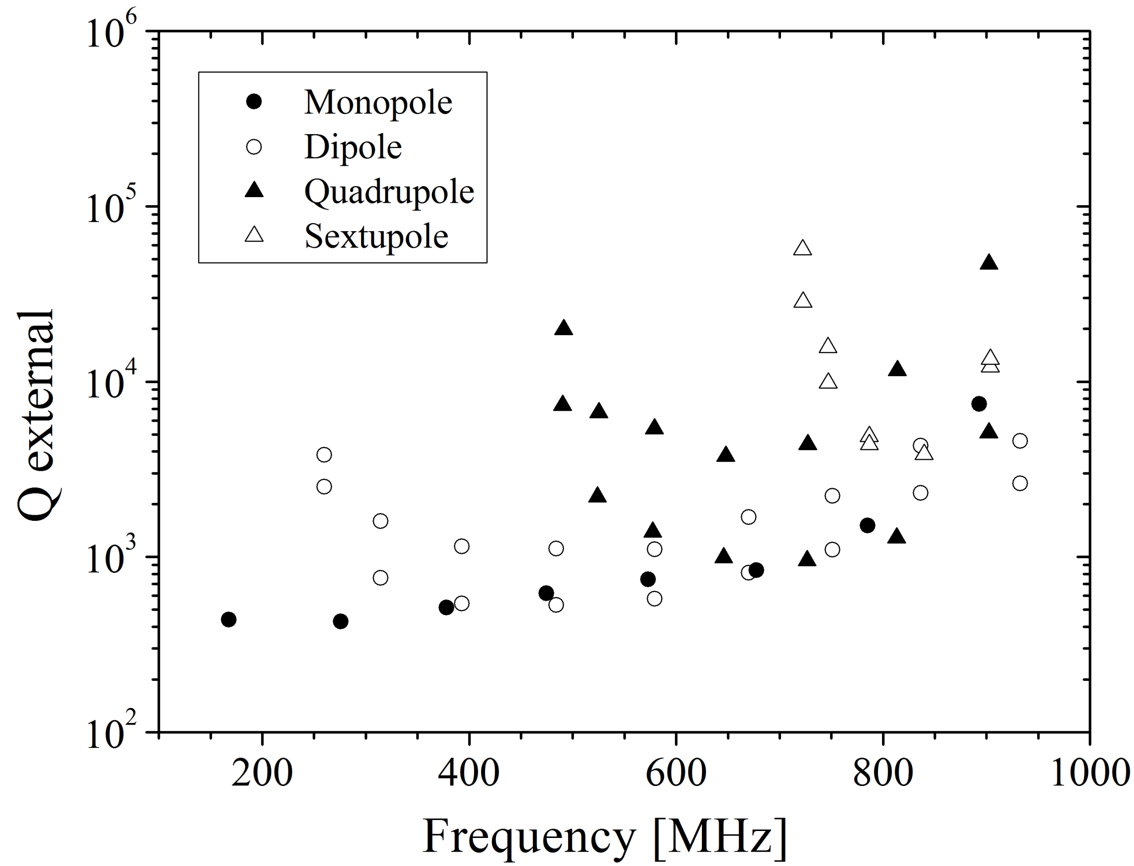




HOM Coupler Configuration (2)

- If one of the couplers is offset by 45 degrees, the Q_{ext} of the insufficiently coupled quadrupole modes are decreased significantly. The consequence of this improvement is a slight increase of Q_{ext} for other quadrupole modes.

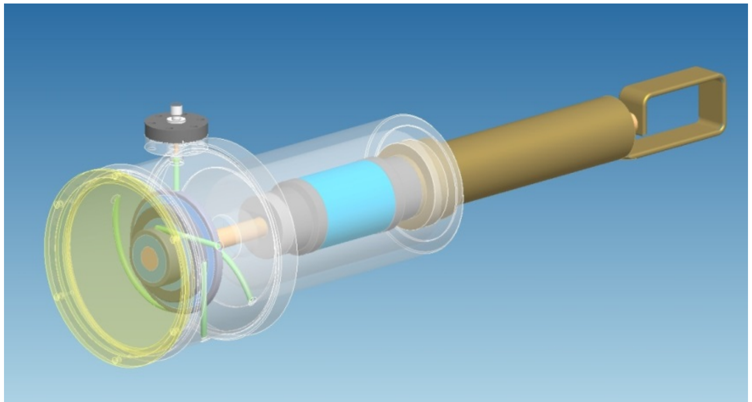


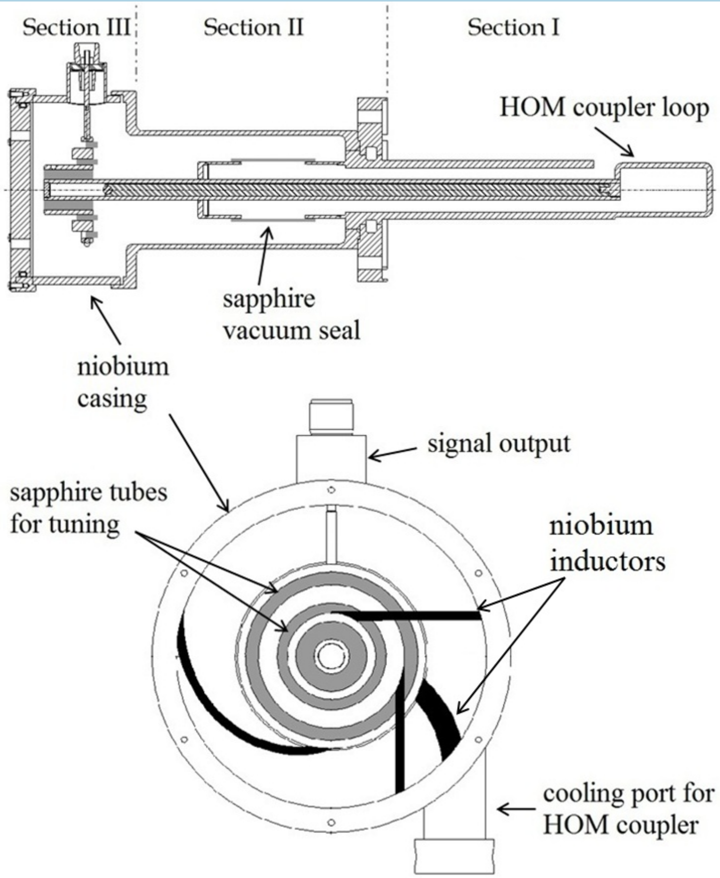


HOM Damper Filter

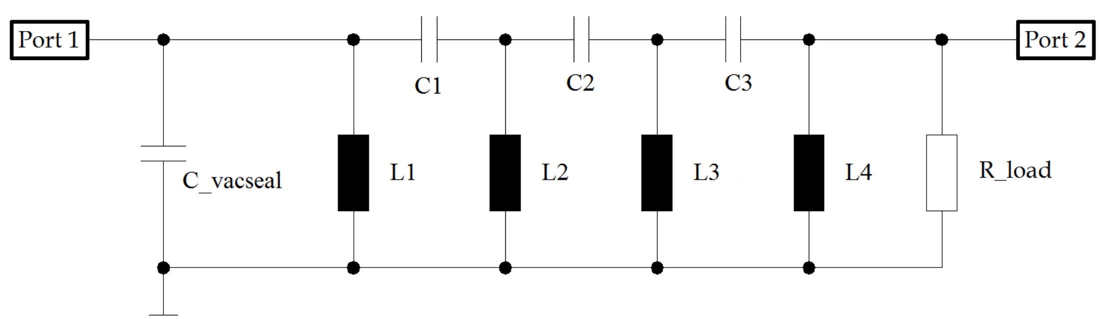
- The fundamental mode is strongly coupled to the HOM dampers.
- Filters are needed to avoid damping of the fundamental mode.
- Due to large separation from the first HOM to the fundamental mode, we have an option of using a high-pass filter.
- The damper loop and the metal components of the filter are all made of niobium.
- The capacitor components of the filter are made with sapphire.
- During operation, the filter is at 4 K.
- The HOM power is absorbed in an external load.
- The HOM assembly cooling scheme utilizes a high RRR copper thermal conductor and liquid helium cooled flange.
- Thermal transition between the filter and the external load occurs along a stainless steel cable.

High-Pass Filter Design

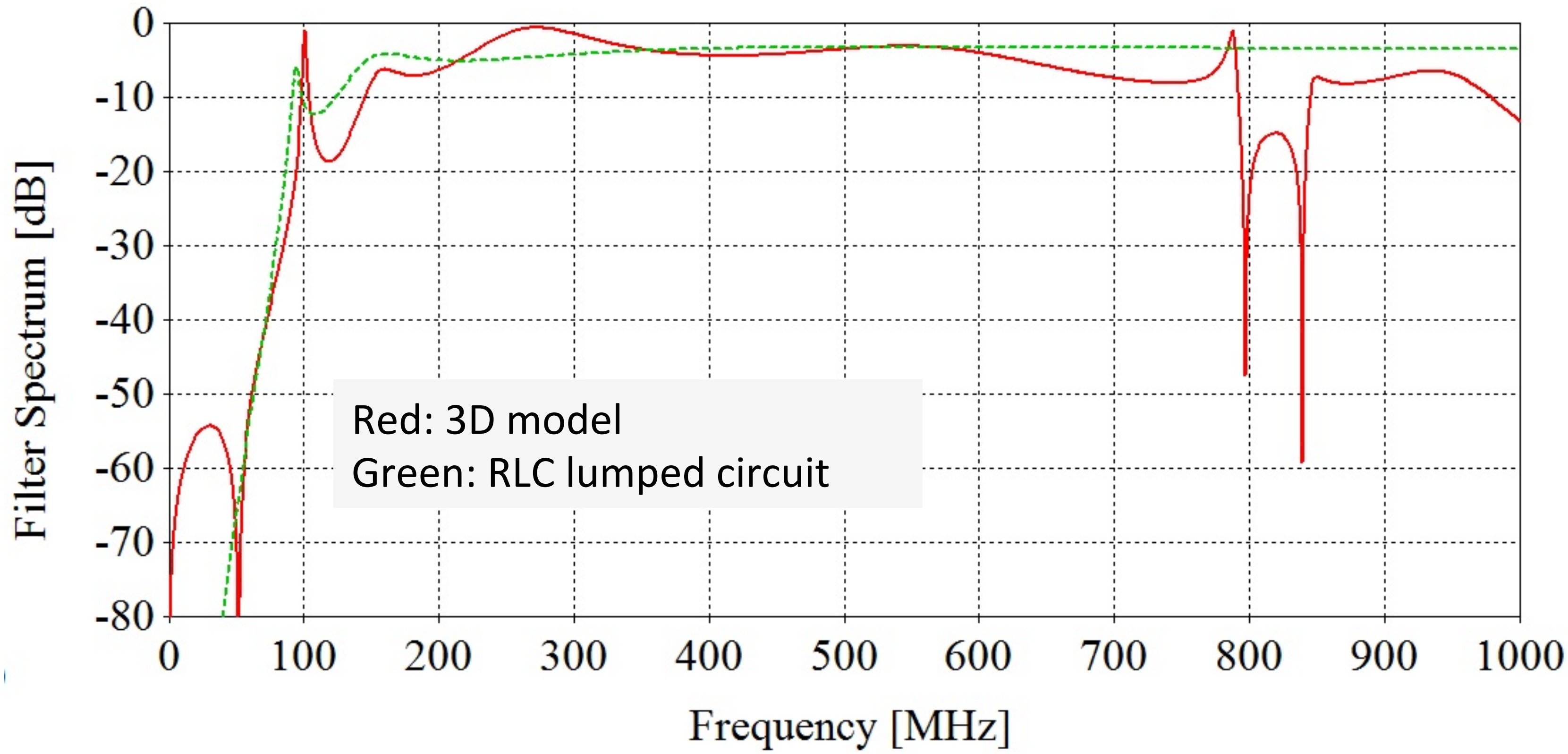




- The high-pass filter has a coaxial layout with niobium and sapphire rings.
- Because it is a very low loss dielectric, sapphire was chosen to minimize the size of the filter at such low frequency application.
- The Chebyshev high-pass filter has 3 stages.
- A cylindrical sapphire window separates the cavity vacuum from the insulation vacuum.

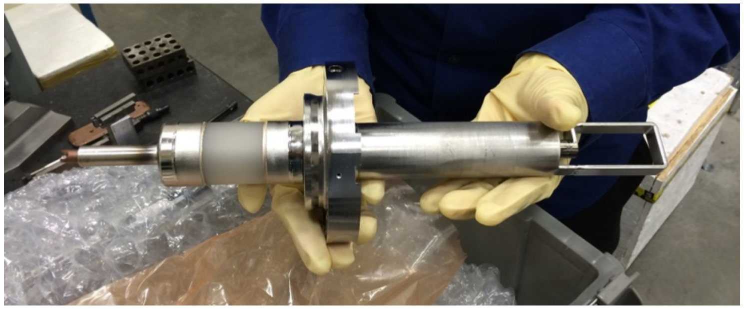


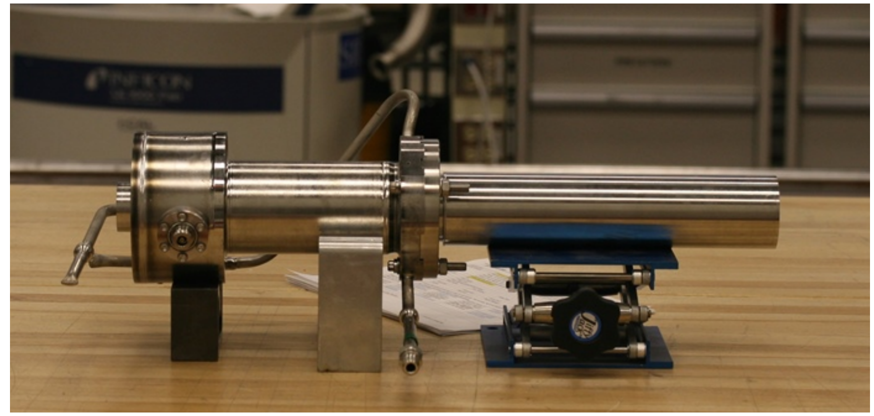
Filter Performance

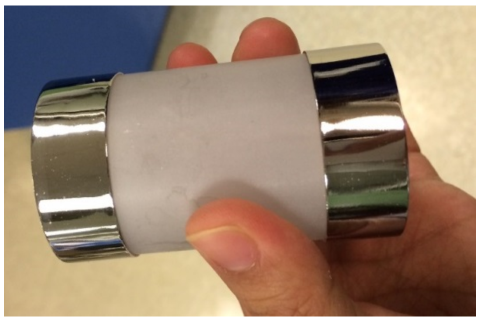


The high-pass filter has a very nice frequency response over the range of 0 to 1 GHz, except for the two notches near 800 MHz. This is caused by the parasitic capacitance between the filter sapphire rings and the end cap of the vacuum seal. However, none of the HOMs of the cavity overlays with the notches. Therefore, the notches do not affect the filter performance, even in the situation when all the HOMs are excited.

Fabrication

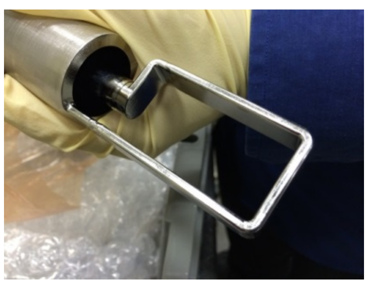




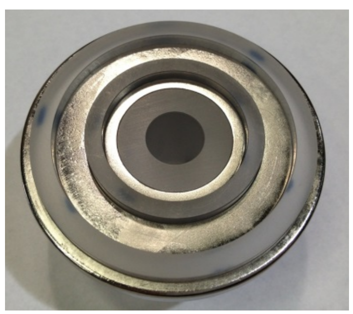


Sapphire window

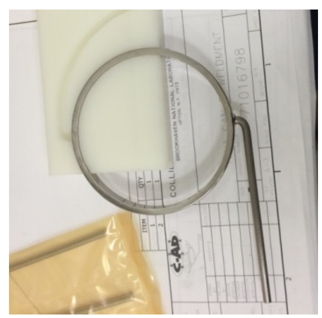
- The first article (prototype) was fabricated at Jlab.
- Some parts were provided by Niowave.



Coupler loop



Sapphire in capacitors

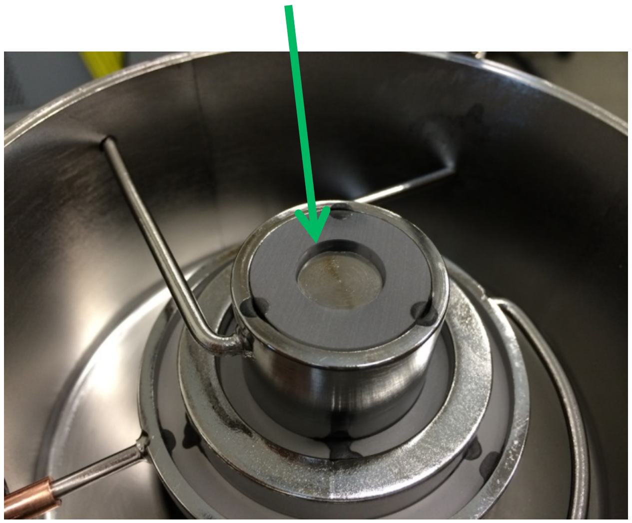


Niobium inductor

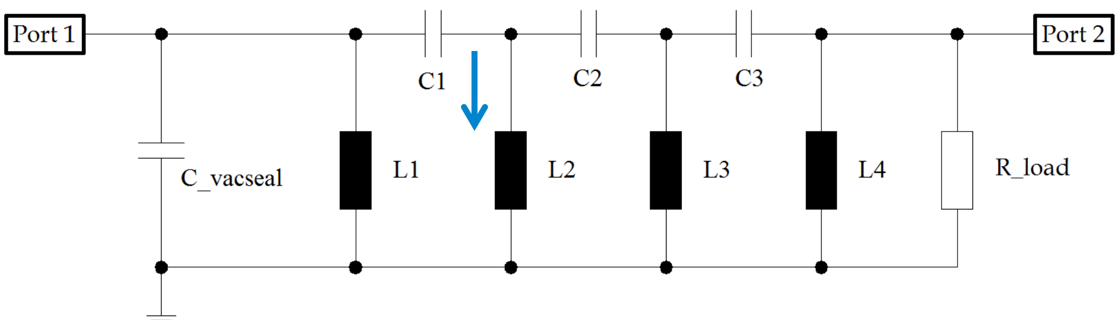
Complete filter assembly

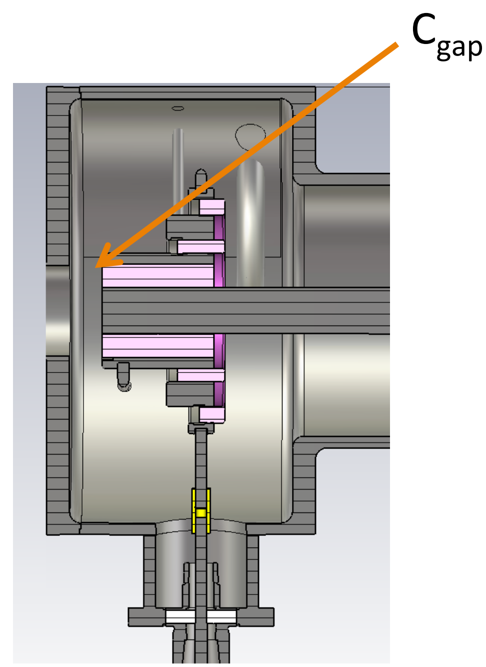
Tuning of the Filter

- The filter can be tuned by sliding the inner most sapphire ring along the center conductor.

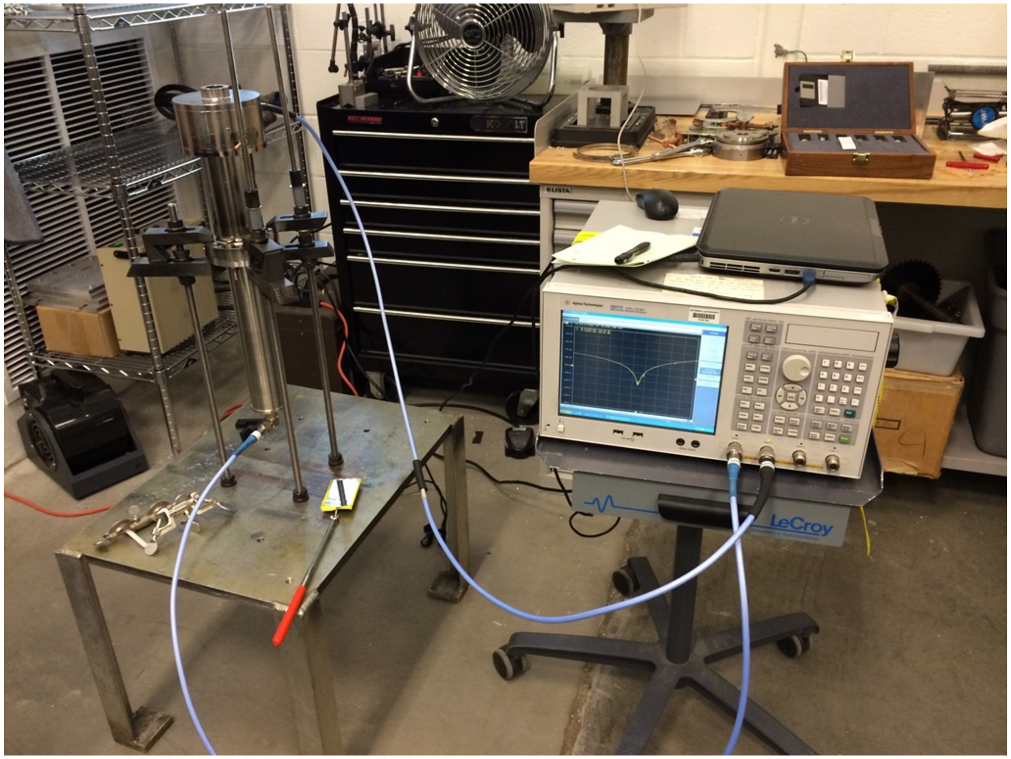


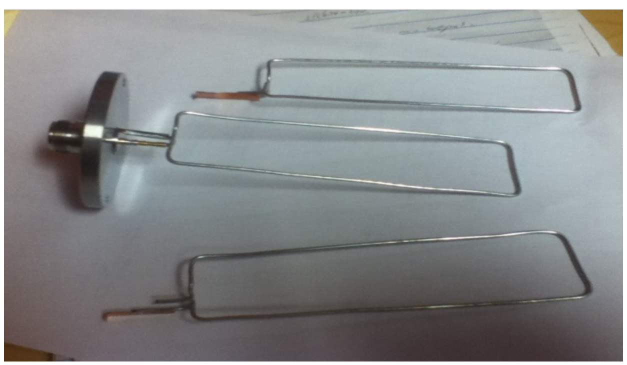
- The capacitance generated between the sapphire and the end cover (C_{gap}) will increase, while the first capacitor (C1) will drop as a result of decreasing the contact surface. A combination of two effects shifts the notch toward lower frequency. The notch was designed to be at a slightly higher frequency before sliding the sapphire tube.





Tuning Set Up



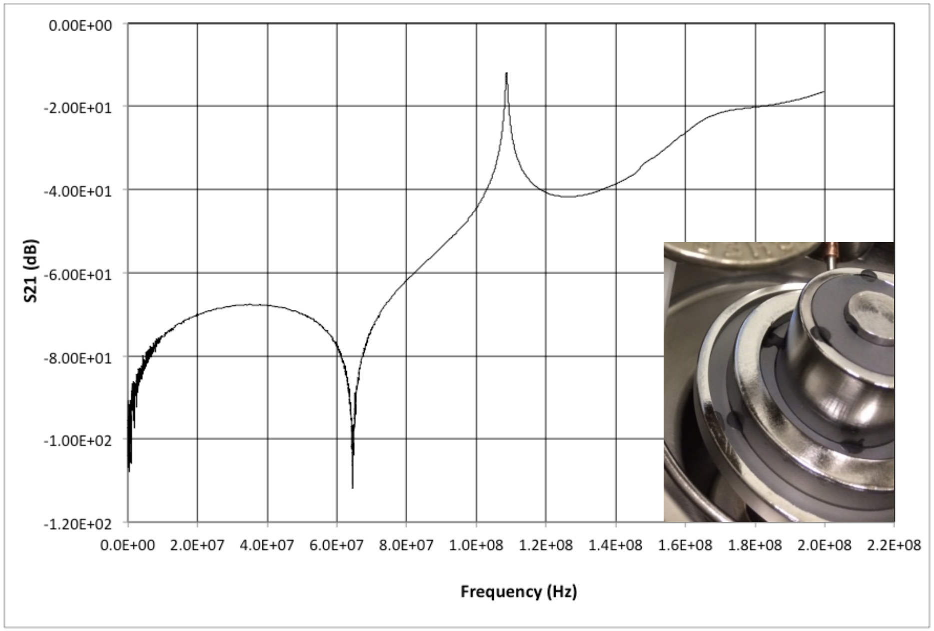


Tuning set up was assembled vertically on a fixture frame. Preliminary tuning was done by Haipeng Wang before the Nb inductors are welded.

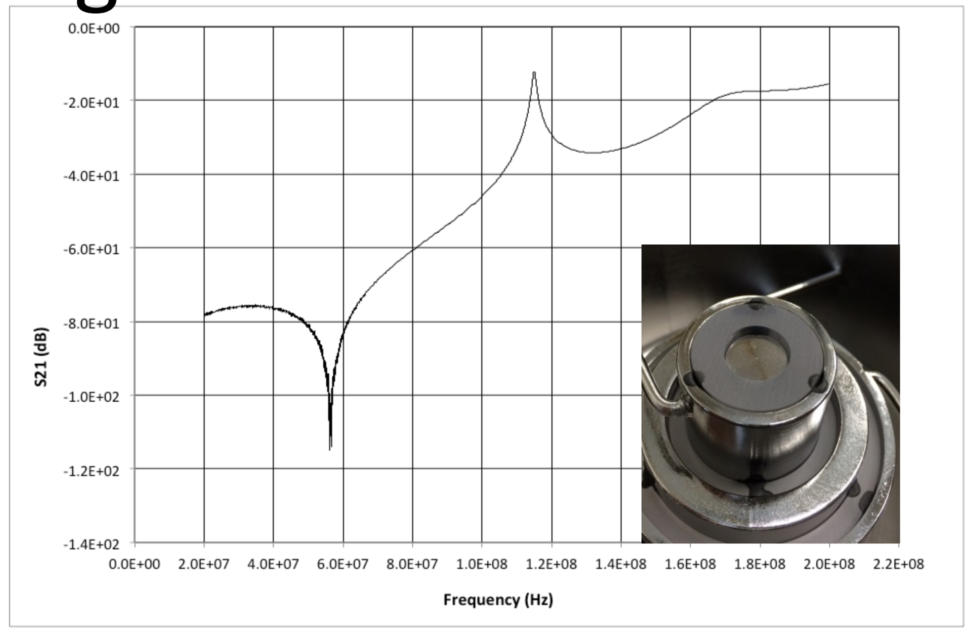
Final tuning was done under the following condition:

- All of the Nb inductors are welded to the tuning can.
- Niobium rings are fixed to the sapphire rings via Stycast before installation.
- A loop antenna is used for broadband frequency scan (bottom left figure).
- HOM coupler loop is enclosed in a tube with antenna.
- End lid was not welded, but available to close the filter can.

Filter Tuning Results



Before tuning: the notch is at 61.8 MHz.
The filter stack slid down due to gravity.



After tuning: the notch is at 56.3 MHz.

At the final location:

- The notch is measured at 56.3 MHz, −110 dB.
- The first HOM frequency of the cavity is at 168 MHz, −20 dB in this coupling set up, which agrees with the MWS simulation.
- The difference between the fundamental mode and the first HOM mode is 90 dB.
- The bandwidth of the notch at −90 dB is 3.7 MHz.

Filter Tuning Results (2)

The final position of the sapphire tube was fixed by applying Stycast to the pre-machined slots.

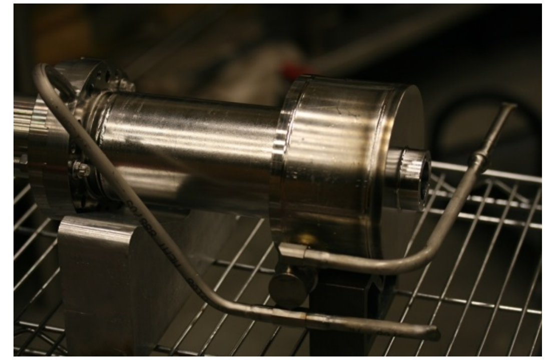
Some remarks:

- 15 micron BCP on the HOM loop and the outer conductor.
- Ultra-sonic cleaning of the entire assembly, with no detergent.
- The inside of the filter can was cleaned by swab BCP.
- Assembly sealed in nitrogen-filled bag for transport.
- Assembled on the cavity in class 100 clean room.
- Unfortunately, we only had one HOM damper, a prototype, ready for RHIC Run14.

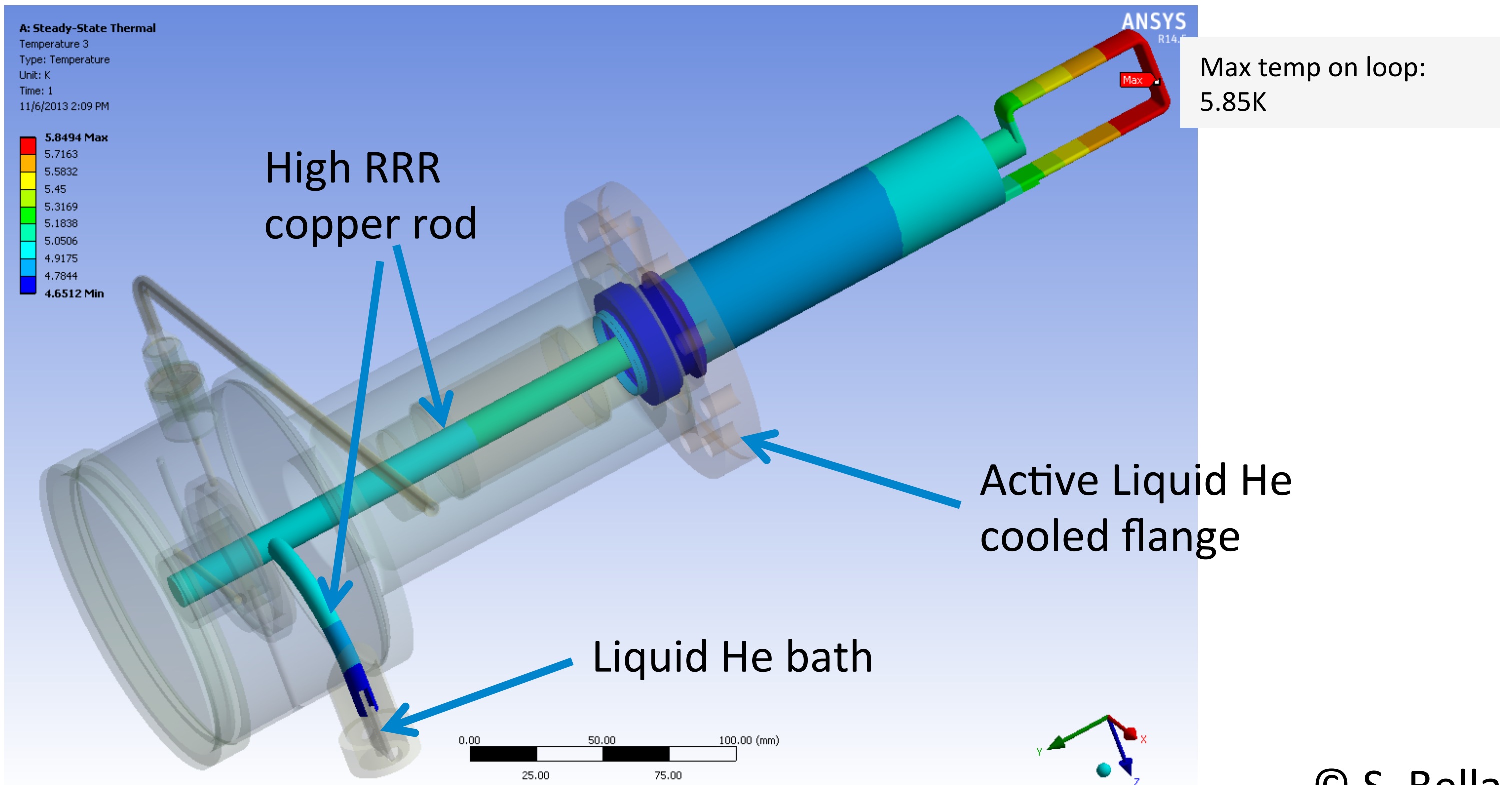
Cooling

Cooling to the assembly was provided in two ways:

- High RRR copper rod heat conductor from filter can to loop;
- Direct liquid He cooling of the flange.



ANSYS simulation was done with MWS simulated power losses:



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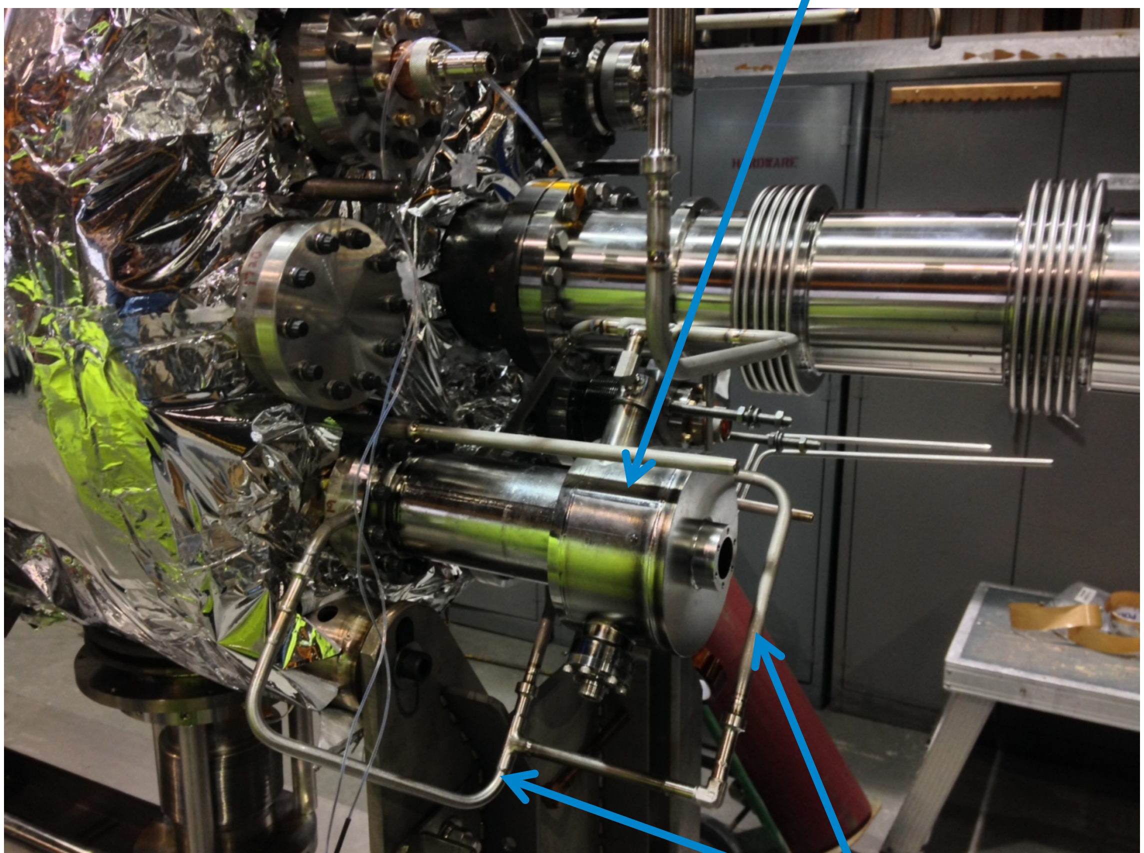
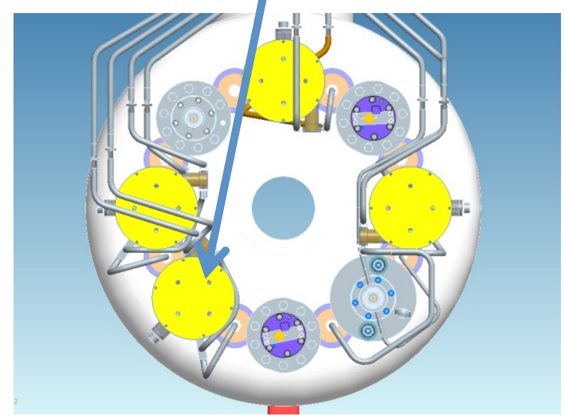
Cavity Assembly

HOM damper



LHe Cooling lines

The HOM assembly is installed at the 225 degrees location. The location is chosen to achieve maximum damping with only one damper.

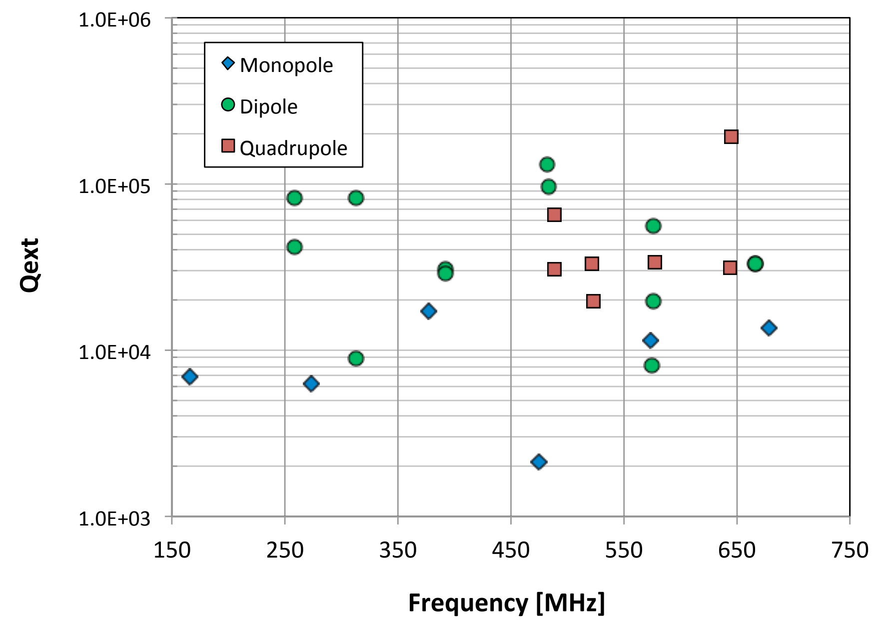


Measurements at 4 K

frequency [MHz]	Qext measured	Q with 4 dampers	Designed Q with 4 dampers	Q Instability limit
56.263541	3.46E+10	8.65e9	1.1e10	
165.9090	6,898	1,725	1,501	2,000
274.0460	6,313	1,578	428	Not specified
377.1053	17,349	4,337	991	25,000
474.7765	2,131.5	532.9	1093	7,000
573.7025	11,490	2,873	975	5,000
678.4498	13,497	3,374	3856	25,000

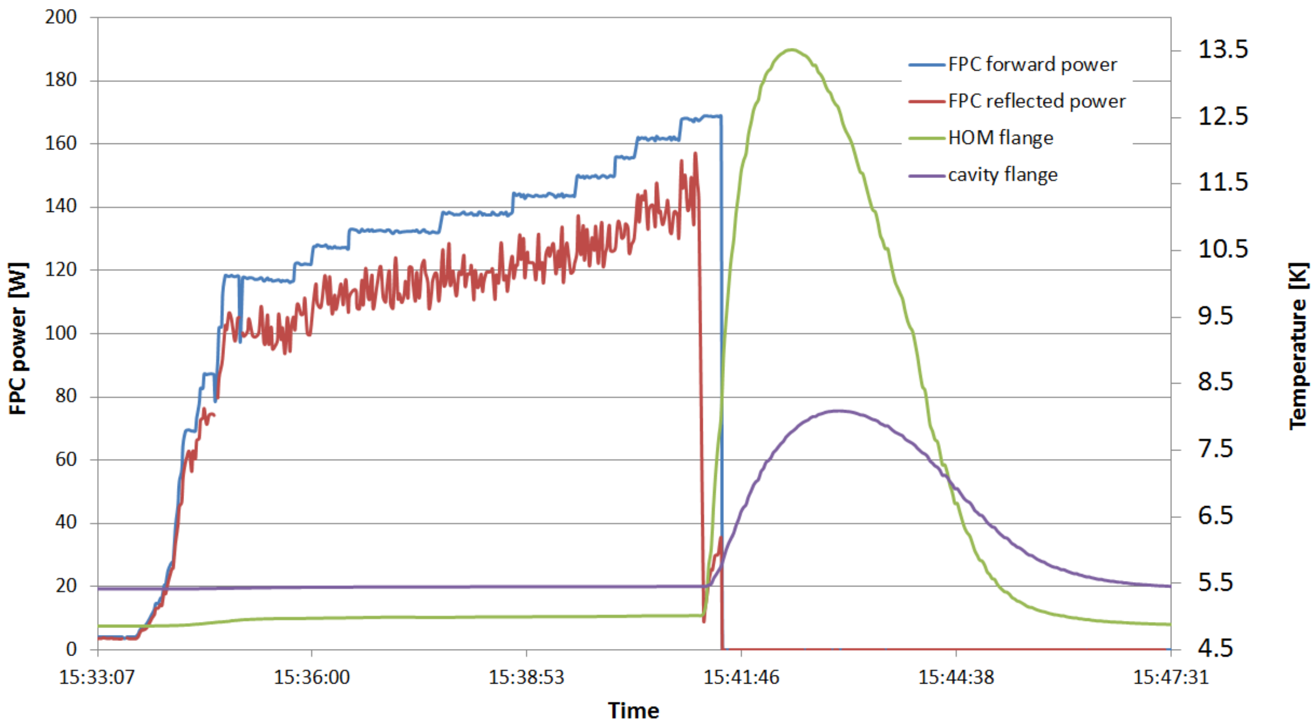
Measured monopole HOM Q_{ext} at 4 K. If extrapolated to 4 dampers, all below specified instability threshold.

Q_{ext} of all dipoles and quadrupoles up to 700 MHz are measured with efficient damping. The expected Q_0 of these modes are all above 1e9.



Quench

- During high power operation, the HOM assembly quenched at ~1/5 of the designed field.
- Temperature sensors are mounted on the HOM damper flange and the mating cavity flange.
- Both temperatures rise slowly with RF field.
- Quench happens as the HOM flange reaches 5 K.



The cause of quench is unknown at this time. Detail thermal simulations are under way.

Summary

- An HOM damping scheme with 4 dampers was designed for the 56 MHz quarter wave SRF cavity.
- The dampers are inserted at the rear end of the cavity in an asymmetrical configuration to provide optimal HOM suppression.
- A three-stage Chebyshev type high-pass filter provides very good rejection of the fundamental mode.
- Tuning of the filter is achieved by sliding the sapphire stack along center conductor. The final position is fixed by Stycast.
- Cooling of the damper is provided by thermal conduction and active cooling on the flange.
- One damper (a prototype) was installed for RHIC Run14.
- Measurements at 4 K show that the damper achieved design Q_{ext} goal.
- Unexpected quench happens at ~1/5 of the design field. Analysis is in progress.

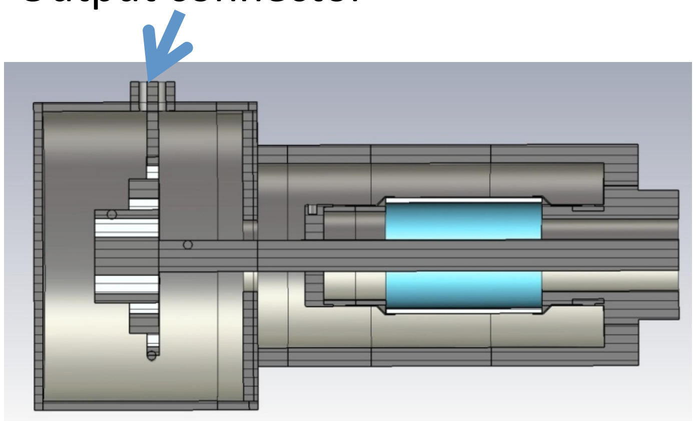
Back-up slide

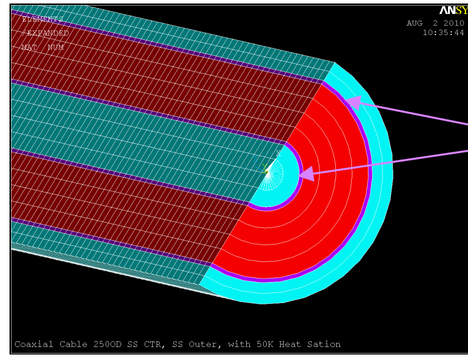
Transfer Cable

Courtesy S. Bellavia

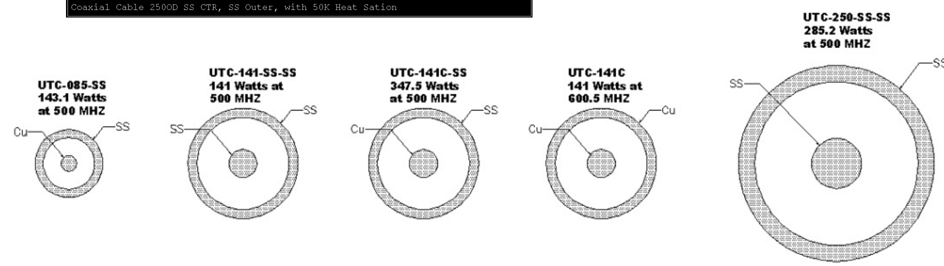
A transfer cable is used to connect the output connector of the high-pass filter (4.5K) and the external load (RT). The thermal transfer on the cable is very important, as we want the least heat to be loaded into the cavity through this connection.

Output connector





These regions made 100X more thermally resistive than PTFE to simulate contact resistance



SS Conductors, 50K Heat Station with effect of Contact Resistance